

A p+deuteron Proton Polarimeter at 200 MeV*

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Abstract

There has been concern about the analyzing power of the p-Carbon polarimeter at the end of 200 MeV LINAC of BNL. A new polarimeter based on proton-deuteron scattering was installed and we have repeated the calibration of proton-Carbon scattering at 12 degrees and 200 MeV against proton-deuteron scattering. The result is consistent with the value of $A=0.62$ now used to measure the beam polarization at the end of the LINAC.

1 INTRODUCTION

The Brookhaven Alternating Gradient Synchrotron (AGS) has been accelerating polarized protons since the 1980s. Over the years, the ion source used at the AGS was a Haeberli-type pulsed polarized negative hydrogen ion source. The output current of the source was about 10 μ A, the polarization was typically 75% [1]. The Relativistic Heavy Ion Collider (RHIC) spin design goal assumes 2×10^{11} proton/bunch with 70% polarization. A new Optically Pumped Polarized H^- Ion Source (OPPIS) was developed for the RHIC spin program [2]. Its current has exceeded requirements for RHIC and polarization reached 75-80% in a recent test. To measure the polarization precisely, the existing polarimeter was first upgraded and then calibrated with the p-deuteron polarimeter.

2 MODIFICATION OF P+CARBON POLARIMETER

When the beam is vertically polarized, the polarization is determined by measuring the left-right asymmetry in the horizontal scattering plane which is normal to the vertical polarization vector. The beam polarization P is given by

$$P = \frac{1}{A} \left[\frac{\sqrt{L_{\uparrow} R_{\downarrow}} - \sqrt{L_{\downarrow} R_{\uparrow}}}{\sqrt{L_{\uparrow} R_{\downarrow}} + \sqrt{L_{\downarrow} R_{\uparrow}}} \right] = \frac{\delta}{A}, \quad (1)$$

where A is the analyzing power of a polarimeter, δ is the raw asymmetry in the counts from the two arms, while L_{\uparrow} (L_{\downarrow}) and R_{\uparrow} (R_{\downarrow}) are the number of spin-up (spin-down) particles scattered to the left and right, respectively. Note that the polarization of the beam from the LINAC is flipped between up and down (\uparrow and \downarrow) on alternate pulses. This formula averages over the beam polarization for \uparrow and \downarrow beam spins, which were generally nearly equal. This formula has the advantage that variations in solid angle and beam current cancel out to first order.

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The 200 MeV polarimeter was placed just downstream of the LINAC. It measured the beam polarization in a separate branch of the injection line before injection into the AGS Booster. The 200 MeV polarimeter consisted of two independent polarimeters each containing a left arm and a right arm. Each arm contained two scintillation counters in coincidence. Each polarimeter measured the asymmetry in $p + {}^{12}C \rightarrow p + \text{anything}$ at 200 MeV, one at a scattering angle of 12° and the other at a scattering angle of 16°. The two measurements were converted into polarizations using Eq.(1) and then averaged to give the final polarization.

The polarimeter was calibrated using the 200 MeV polarized proton beam at Indiana University Cyclotron Facility (IUCF), and the analyzing powers of the 12° and 16° arms were found to be 0.620 ± 0.004 and 0.511 ± 0.004 , respectively [1]. The polarimeter provided a fast, absolute measurement of the beam polarization with a 1% statistical precision in about 5 minutes. It was observed that the polarization measured at 16° was 5% higher than the one measured at 12°.

Since the installation of the new OPPIS polarized ion source, beam currents at the end of the LINAC have increased substantially to 200 μ A. At this current, the scintillation detectors used to observe proton-Carbon scattering at 12° and 16° arms overloaded and polarization measurements were unstable. To combat this problem, the horizontal plane detectors at 12 degrees were moved to a much larger distance. Lead shielding and a collimator were included to restrict the observed charged particles to an origin at the target. With current reduced to the 10 μ A level, the polarization from 12° and 16° arms agreed within error bars. At the same time, the optics of this part of the beam line were improved to make a tighter beam spot in the hope that this would reduce the contribution from scattering off thick parts of the target ladder. On a strip target, however, this improvement tends to increase the rate. This raised the question of whether the calibration, made in 1982 at IUCF [3], and reported in 1989 [1], remained valid.

3 P+DEUTERON POLARIMETER

Knowing the polarization at the end of the LINAC is crucial in evaluating whether there are significant losses in the polarization as the beam goes through the Booster and the early stages of AGS acceleration. It was suggested earlier last year that if a setup could be constructed that would observe p+d elastic scattering, then it would be possible to make use of the very precise analyzing power measured at IUCF[4]. For a deuteron recoil angle of 42.6° in the lab and a laboratory energy of 200 MeV, the analyzing power

is known to be $A = 0.507 \pm 0.002$. The analyzing power measured at IUCF as function of beam energy is shown in Fig. 1. At the same time, the cross section is 2-3 orders

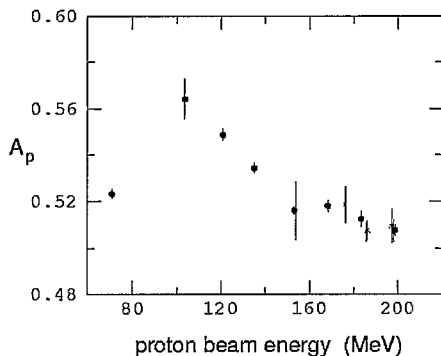


Figure 1: Measured analyzing power from IUCF.

of magnitude less than that for proton inclusive scattering. So p+d scattering cannot yield polarization values within a few minutes as do the 12° counters based on p+C scattering. One way to proceed is to use p+d scattering in a longer run to calibrate p+C scattering, which would then serve for routine measurements. Thus the design of the running involved interleaving p+C and p+d runs by swapping targets under conditions where the beam polarization was believed to be sufficiently stable to permit good time averages to be computed.

The detector setup is shown in Fig. 2. Scintillators were gathered and mounted in a new setup. A series of CD_2 targets were installed on the target ladder next to the existing carbon target. The deuteron detector telescope consisted of three scintillators with an aluminum absorber in front whose thicknesses were chosen so that deuterons from p+d scattering would stop in the second scintillator. The third then became a veto. The two proton arm detectors for each side were salvaged from the 16° p+C setup where they had run without absorbers. At $\theta_{\text{lab}} = 64.1^\circ$, the scattered proton angle, we ran with a 2.54-cm thick aluminum absorber. Protons from p+d scattering still traveled all the way through both detectors, but the energy deposited exceeded by a significant amount the energy from protons scattered near beam energy from carbon. The front ΔE scintillators and the back veto scintillators in the deuteron arms were made smaller to reduce random rates.

The data was acquired by FERA readout into a CAMAC buffer. This allows several events to be recorded and stored during a single beam pulse without the overhead of CAMAC readout into a computer.

The calibration consisted of interleaving p+C runs with p+d runs. The ratio of the beam polarizations measured with these two systems was a check of the p+C calibration. Additionally, scaler readout with the CD_2 target was made using both p+C rates and p+d coincident rates to see whether either of these could also serve as a measure of the beam polarization.

Switching of the beam from the Booster to the straight-

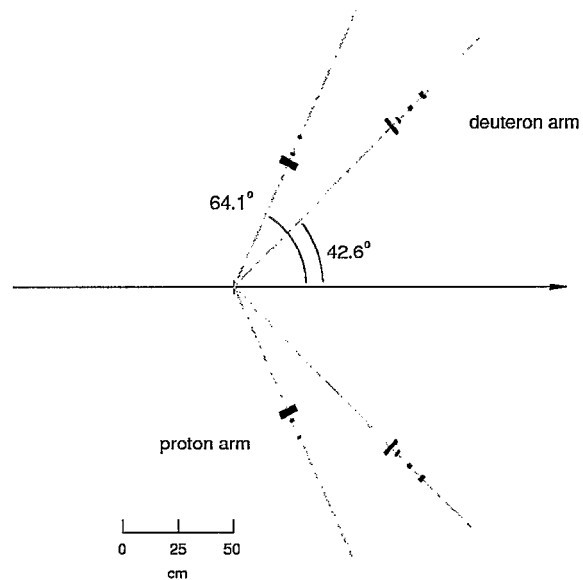


Figure 2: p+d polarimeter setup at BNL LINAC. This is a scale drawing showing the scintillator placement for deuterons at 42.6° and protons at 64.1° . The large pieces at the front of each telescope are aluminum absorbers placed to reduce the rate from inelastic protons.

through line at the LINAC where the polarimeter is located was developed, thus permitting calibration runs to be made in parallel to the AGS spin development. To reduce the rate for the p+d system, one of the quadrupoles was defocussed, also in beam sharing mode, so that the calibration was made at a smaller current. This procedure may increase detector rates if the tails of the beam reach the target frame.

Despite improvements to the data acquisition, the overall p+d rate turned out again to be low. In part, this was due to the fact that with beam sharing, only 1 pulse every 5 seconds was available in the polarimeter line. Second, for reasons discussed in more detail later, rate problems with the p+d scintillator systems forced us to operate at the edge of the beam spot where currents were effectively less than about $20 \mu\text{A}$, again cutting rate. Thus the calibration was spread out over four days of running.

During the calibration, beam polarizations recorded by p+C scattering varied between 0.67 and 0.71. These variations were treated as real, and could be associated with changes in the operation of the ion source between pulsed and dc mode in the ionizer. The changes from one mode to another serve to keep the ionizer cleaner, and this helped to maintain a higher polarization. Beam polarization ratios between p+C and p+d scattering were calculated only for runs that came together during a single mode. Only the ratios were averaged over the whole calibration.

The electronics was set so that only the higher pulse height signals associated with p+d scattering were allowed to generate the logic signals going into the coincidence between the deuteron and proton arms. In addition, even

higher cuts were placed on the pulse height signals for analysis. Upper cuts were avoided since there was evidence for pileup of real events in the pulse height spectra. The time peak for p+d scattering was narrow. Summing was made in the time spectrum, gated on correct scintillator pulse height. A small background of randoms, no more than a few percent, was subtracted from the time peak as needed.

The ratio of the beam polarization measured with p+d scattering to that measured with p+C scattering was found to be

$$p_d/p_C = 0.988 \pm 0.017, \quad (2)$$

a value consistent with one. Detailed polarimeter measurements for each stable ion source cycle are listed in Table 1. Based on these results, there is no need to change the analyzing power of p+C scattering currently in use.

Table 1: Partial Results from calibration run

Run	$p(p+C)$	$p(p+d)$	p_d/p_C
1	0.673 ± 0.004	0.663 ± 0.023	0.986 ± 0.035
2	0.703 ± 0.006	0.693 ± 0.044	0.986 ± 0.063
3	0.673 ± 0.005	0.688 ± 0.024	1.023 ± 0.036
4	0.722 ± 0.007	0.776 ± 0.044	1.074 ± 0.062
5	0.722 ± 0.007	0.802 ± 0.048	1.112 ± 0.067
6	0.710 ± 0.005	0.656 ± 0.020	0.924 ± 0.029
ave.			0.988 ± 0.017

4 SYSTEMATIC ERRORS

The main difficulty with both the p+C and p+d systems was the sensitivity of the photomultiplier tubes to rate.

In the p+d case, too high a rate would cause the gain to drop, and the signals of interest would fall below the discriminator cutoff. Under different running conditions, gains were observed to change by a factor of a few. In all cases, measurements were made at rates that caused the PMT gain to saturate, a phenomenon that could easily be observed by tracking the time dependence of the falling pulse height at the beginning of the LINAC pulse. While the beam current was 50 μ A, the CD₂ target was placed at the edge of the beam in such a place that the effective current was in the range of 10 to 20 μ A. Only at this level was it possible to keep the p+d signals above threshold with enough efficiency that the rates for left and right scattering were comparable.

For the p+C system, there is also a reduction in photomultiplier gain with increasing rate. Here the effects are not as severe. Since the positive analyzing power is associated with the primary proton rate into these scintillators, the effect of reduced gain shows up as a smaller polarization value. A number of tests were made during the course of the run comparing p+C measurements at 50 and 200 μ A. Fig. 3 shows two such scans in which the beam current was

controlled by defocussing LINAC quad 14 (solid points) or closing slits near OPPIS (open points). For both scans, polarizations are divided by the polarization at the lowest rate (37) to show the percentage reduction. Additional checks gave qualitatively similar results. It is important to keep these changes in mind when interpreting the results of the scaler readout. This reduction may have contributed to the differences between 12° and 16° p+Carbon measurements of the beam polarization.

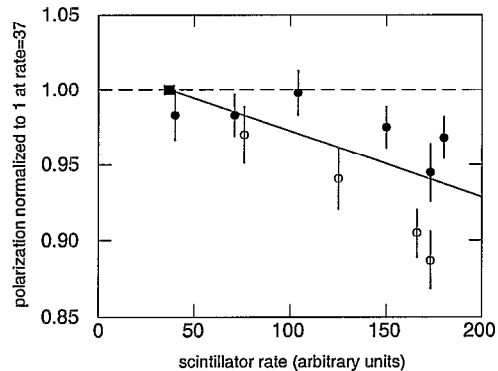


Figure 3: Measured Polarization (p+Carbon) dependence on beam intensity. The horizontal axis is scintillator rate in arbitrary units (the rate values correspond roughly to LINAC beam current in μ A). A linear fit is included as a guide to the eye.

The experience with rate limitations suggests that there are systematic effects whose contribution to the calibration error exceeds the statistical error quoted above. An estimate of 0.02 or even 0.03 would appear to be appropriate.

5 SUMMARY

We have repeated the calibration of proton-Carbon scattering at 12° and 200 MeV against proton-deuteron scattering. We find a result of the analyzing power for proton-Carbon scattering that is consistent with the value of $A_N = 0.62$, now used to measure the beam polarization at the end of the LINAC. Both p+C and p+d scattering measurements were subject to rate-dependent problems, and systematic errors in the results may be as large as a few percent.

6 REFERENCES

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